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TURBULENT DIFFUSION AND REAERATION IN NATURAL RIVERS

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PROGRESS REPORT

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TURBULENT DIFFUSION AND REAERATION IN NATURAL RIVERS

VANDERBILT UNIVERSITY

Peter A. Krenkel
Project Director

Report covers period June 1, 1968, to May 31, 1969

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2. SUMMARY STATEMENT

The second year of this project saw the initiation and accomplishment of a large portion of the field work. The first year had been devoted largely to planning, orientation, preliminary field work, and data compilation.

The field project during the summer of 1968 was designed to demonstrate the feasibility of using refined tracer techniques to measure mixing and diffusion taking place under non-steady, non-uniform flow conditions. Specifically, the test demonstrated the feasibility of using fluorescent dyes to trace polluted water, traveling as a power wave, into and through a stratified impoundment. Measurements of longitudinal, lateral, and vertical mixing were made to demonstrate the feasibility and ease of this technique in determining mixing coefficients, which can be used to predict the spread of polluted inflows in a stratified environment.

Work continued through both the summer and winter on testing of recently-developed theoretical mathematical models describing reaeration and mixing in natural streams. The work should be completed within a year if money is provided for field work during the summer of 1969.

3. STATEMENT OF PROGRESS

(a) Activities and Accomplishments - The objectives of this project, as stated in the grant application, are:

1. To measure reaeration rates and relevant turbulence parameters under controlled conditions.

2. To test the applicability of recently developed theoretical mathematical models describing reaeration and mixing in natural rivers.

3. To determine the utility of refined tracer techniques in describing mixing phenomena in unsteady-state flow conditions and stratified flow.

During the first year of the project, field work was hindered by bad weather and the emphasis was placed on objective number two. A large portion of this objective has been accomplished, using previously acquired but unpublished mixing data. To complete this objective, the data to be taken under objective number one will be needed.

The reaeration prediction model which was to have been tested during the field work phase of this project was one developed on a laboratory scale in a two-foot wide flume at Vanderbilt by E. L. Thackston and P. A. Krenkel, and successfully tested with the natural stream data of Churchill, Elmore, and Buckingham, and that gathered by O'Connor and Dobbins. However, the predictions differed from those obtained by the earlier model of Krenkel and Orlob, derived from data from a one-foot wide flume, by a factor of approximately 2.2. Field demonstration of the predictive ability of the new reaeration model was deferred until the conflict between the model of Thackston and that of Krenkel was resolved. This was thought necessary, because the discrepancy might have been due to an unknown factor which would not have measured or

controlled during the field work.

Since extensive checking of both sets of original data revealed no errors, and the slight difference in saturation values of dissolved oxygen used were determined to have a negligible effect, re-runs of both experiments were performed. Experiments essentially identical to those of Thackston were performed by other personnel, using all new chemical solutions, and the results were identical to Thackston's as shown in Figure 1. During the winter of 1967-68, a one-foot wide flume was constructed and inserted into the original flume. (The width was the only significant difference between the flume used by Thackston and that used by Krenkel).

Experiments were conducted with various treatments of the bottom and sides to produce different roughnesses. They were:

(1) One-foot flume with only bottom roughness

(2) Same as (1) with dowelling for sides

(3) Same as (1) with wire mesh on sides

(4) Eight-inch channel with no side roughness

The runs made with the plain one-foot channel were for the purpose of supporting or refuting Krenkel's data. The results are shown in Figure 2. The values for k_2 vs. u_*/h follow very well the straight line relation, as predicted by Thackston. Although the two lines do not coincide, they are very near one another. Thus, Krenkel's data are not erroneous, but are truly representative of conditions in a one-foot channel, and the width of small flumes does apparently have some effect on the reaeration coefficient.

Krenkel's channel was made of jointless cold-rolled steel. Joints

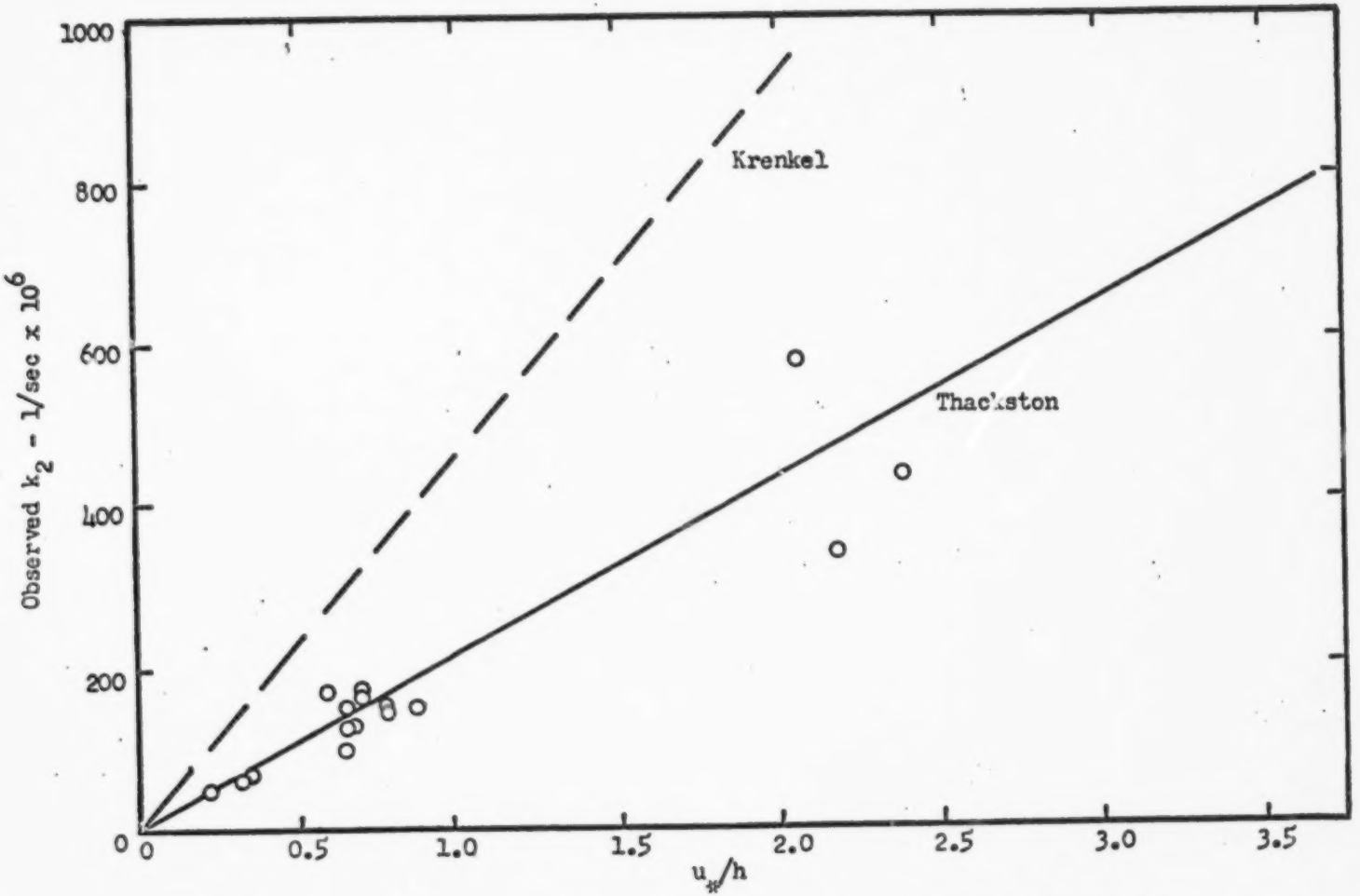

Figure 1.—Additional Data on two foot Flume shown with Thackston's Line

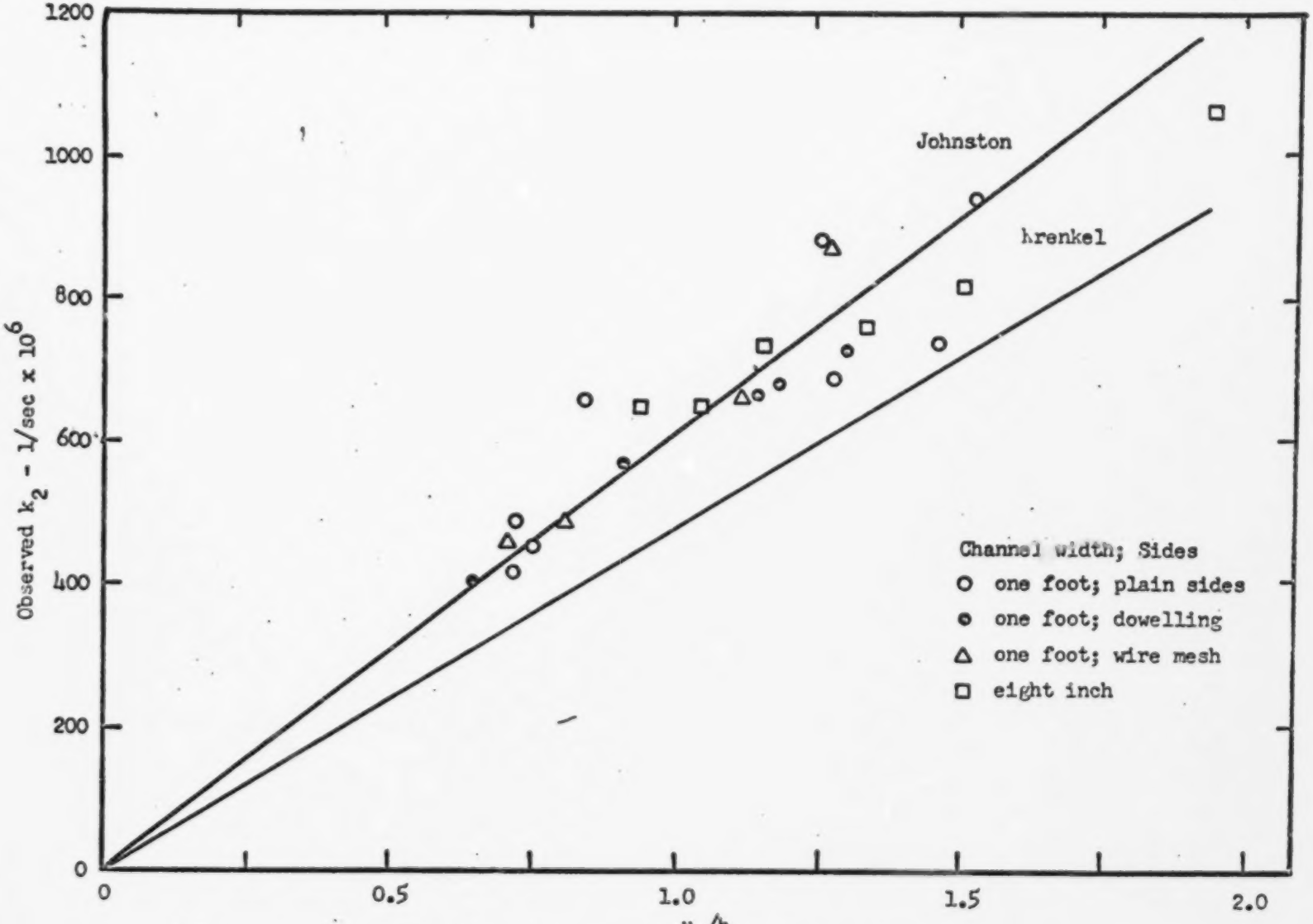

Figure 2.--Relation of k_2 to u_*/h in Laboratory Channels

seem to play an important role in generating turbulence in the wooden flume used in this experiment. Also, it was noted that the wooden flume was not made with a perfectly level bottom. The depth was somewhat variable and required averaging. It was assumed that the data were accurate and that the slight increase in slope of the new data as compared to Krenkel's was a result of either the bottom irregularity or the turbulence caused by the joints.

Since it was difficult to alter the conditions of the first of these choices, it was decided to tamper with the latter choice, i.e., to provide more turbulence by adding roughness to the side. The objective was to simulate the conditions created by the channel joints. Dowelling seemed to create roughly the same type of turbulence.

The idea that the difference was caused by extra turbulence generated by the rougher sides was not supported by the evidence. Points from this series of channel runs fell on the line previously established, as shown in Figure 2.

It was thought that possibly not enough turbulence was generated by dowelling. Wire mesh might have more success. Runns made with this treatment of the sides showed no more change than those made previously, as shown in Figure 2. Thus, the difference in data from this experiment and Krenkel's experiment cannot be attributed to variations in side roughness.

Explanation was attempted by using an eight-inch flume. Since data from one- and two-foot flumes differed so drastically, it was hypothesized that a further change in channel width would produce even more different results.

Data from this series of runs are also shown in Figure 2. Conclusively, they show no relation between channel width and the reaeration coefficient for widths less than one foot. As stated earlier, lateral velocity profiles were taken in the one-foot flume. Since the velocity gradient was not pronounced, it was felt that this profile would resemble that in a two-foot flume. Consequently, no extra k_2 would result from or be indicated by the profile.

Lateral profiles of oxygen concentration were also sampled for, but were undetectable within the range of accuracy of the oxygen titration test (about 0.02 mg/l).

It is felt that this work has now pointed to Thackston's model as the preferred model for field testing, and has eliminated the possibility of roughness variations influencing the model. We are now ready to begin field testing of the model in long non-uniform reaches of streams below TVA impoundments, assuming money is made available for field work during the summer of 1969.

At the same time that aeration tests are being made, dispersion tests can also be run, furnishing the data to complete the work on objective number two. We feel that the gathering and testing of this data will be of great value to the profession, since it will extend the range of confident usefullness of these models past the area of uniform flow (seldom encountered in nature) to non-uniform flow (which is the situation faced most often by sanitary engineers and water quality management engineers). Preliminary work has indicated that these models are indeed applicable to non-uniform flow conditions, but only more field testing will definitely confirm this. It is anticipated that the major effort

during the third year of the project will be directed toward completion of the work on these first two objectives. Planning is underway toward accomplishing this goal.

The field work for 1968 consisted essentially of two projects. The first was designed to demonstrate the feasibility of using small quantities of inorganic ions as tracers in stream and reservoir systems. Generally, inorganic ions are regarded as poor tracers because of the enormous quantities required for large streams and long travel times. This is necessary because of the need for concentrations at the sampling point to be well above background levels and also well above the limit of detectability of the analytical method used. We have proposed that these limitations can be overcome by picking as a tracer an ion with a near-zero background level, and by using neutron activation analysis as the analytical method.

In order to demonstrate this method, two tests were conducted during 1968. On April 15, 1968, approximately 100 pounds of iodine were injected into the effluent canal of TVA's John Sevier Steam Plant, just upstream from Cherokee Reservoir. On June 21, 1968, approximately 100 pounds of bromine (as NaBr) was injected at the same location.

According to temperature profiles in Cherokee Reservoir made at the time of the April test, the inflow containing the iodine went into the surface layers of the stratified reservoir. During this period the reservoir was being filled after the winter flood-season drawdown. Very little discharge occurred until about June 15. Starting on that date, samples were taken from the scroll case of the turbines at Cherokee Dam, 55 miles downstream, each day that discharge occurred. This continued

throughout the summer and fall until December. The samples were then collected and sent to Oak Ridge National Lab for analysis.

The objective of the tests was to determine actual times of passage through the reservoir for the different patterns of stratification existing in April and June. The times are expected to be several months, since during the summer, all inflow enters the reservoir above the thermocline and all discharge is taken off below it. Thus, little tracer will reach the outlet of the dam until the thermocline has been drawn down to the low-level turbine intakes or the fall overturn has occurred.

The success of this test will demonstrate tracer capabilities far exceeding anything which has been reported in the literature for deliberately injected tracers. The longest reported tracer tests have been on the order of days, while this tests may extend this to many months.

Preliminary analytical results indicate that the test was successful. A sample taken during June showed an iodine content below the limit of detectability of the analytical method, while a sample for December showed a concentration five times the analytical limit. Enough samples will be analyzed to provide a complete flow-through curve at the dam for both ions. Since two different ions were used, two separate flow-through curves can be measured at the dam even if the tracer clouds are mixed together, partially or completely. Thus, the time-of-passage can be determined under differing conditions of stratification.

The major field work effort of the year involved tagging two power waves entering Cherokee Reservoir on the Holston River with fluorescent dye and using the dye tracer to follow the water into and through the reservoir. The tracer information was used to calculate mixing coefficients

applicable to the stratified environment. These were compared with stability information derived from temperature profiles to determine the extent to which movement of inflow correlates with stability.

The major report is in preparation describing the tests and the results obtained. Copies should be available by June 1 and will be forwarded at that time. A short abstract of the report follows immediately and a preliminary draft of the report is attached to this progress report. The graphs referred to in the following abstract can be found in the report.

On June 13, 1968, 216 lbs of Rhodamine B dye (540 lbs of 40% solution in acetic acid) were injected continuously from 0800 to 1400 EDT into the spillway of the diversion dam at John Sevier Steam Plant. At that time the water temperature ranged from 20.5 to 21.5°C. Again, on July 10, 1968, 108 lbs of Rhodamine B were injected from 1800 to 2400 EDT and the water temperature ranged from 24.0 to 25.0°C. The first injection was into the coldest water passing the dam that week; the second was into the warmest that week.

The graphs in the report show the progression of the dye through the reservoir. The first injection was followed from June 14 to June 27. From June 25-27, there were severe winds on the lake gusting to 30-35 mph which interfered with sampling and resulted in almost complete destratification of the upper 25 feet of the lake and dispersion of the dye cloud. The second injection was followed from July 11 to July 18.

In both runs the dye went through the reservoir in the epilimnion at about the temperature of water at the time of injection or higher. During the first test, a weak thermocline developed at about elevation

1030, between 20° and 22°. No dye sank below this level. Above this sharp bottom edge, it mixed upward, but the center of the cloud stayed at or a few degrees above the initial temperature of the tagged water.

By the time of the second test, the thermocline was lower, and the warmer tagged water entered the reservoir somewhat above the thermocline. Here it mixed both upward and downward, but again, the center of the cloud stayed at about the temperature of the initial tagged water.

Even during the first test, when most of the dye ducked to a depth of 25-30 feet, some appeared in the surface layers, with a relative void separating them. This is believed to be due to warming of dye lagging behind the main cloud, trapped or lagging along the banks, and receiving more solar heating and being influenced more by the warmer water from the North Holston following the tagged cold slug from the South Holston.

Both tests show relatively fast die-away of high-concentrations, with dilulutions of 40:1 in 7 days. Since around-the-clock pollution upstream of the reservoir would enter water with a range of temperatures and tend to enter the reservoir at different elevations, essentially the whole upper layer is available for dilution and assimilation. During 1968, this was about 30 feet in June and 60 feet in July. This is partly due to the fact cold water is being withdrawn from below the thermocline and warm water added above it.

Many creeks and embayments at least as deep as the dye cloud were checked for the presence of dye both while the dye cloud was adjacent to them and after the cloud had passed. No significant ammounts were found. Therefore, from the middle of June to the middle of July, no pollutants in the epilimnion will travel into the creeks and embayments

as long as the lake elevation is falling, with the only possible exception due to the surface being moved by the wind. However, in May and early June, when the reservoir is filling rapidly, it is possible for pollutants to move into the creeks and embayments.

Vertical and longitudinal mixing coefficients were computed and compared to those found in the literature. Vertical mixing coefficients were somewhat smaller than those reported to have been derived from changing temperature profiles, but compared favorably with other reports. Stability infromation could be used to predict the path of the dye with fair certainty.

(b) Significant Problems

The only major problem arising in the second year of this project was the general problem of manpower. When this project was originally formulated, there were assurances of manpower support from the TVA Engineering Research Lab, and it was assumed that temporary field crew personnel could be recruited from among technicians and graduate students at Vanderbilt.

The recent budgetary limitations placed on all federal agencies, and the rapidly growing TVA work load eliminated the possibility of help with the field work from TVA. Their aid was necessarily limited to coordination, loan of equipment, data provision, etc. The growth and maturing of the academic and research program at Vanderbilt eliminated the other source of temporary personnel, which had been used extensively in 1964-66. Most graduate students now have work of their own, and cannot spare the time to participate in other projects. The lab technicians are needed full-time in the labs, now that the program has grown so much in scope, and cannot leave their regular duties serving all projects to participate in a field trip.

Thus, the field work has been accomplished with a smaller staff than originally anticipated. This has been partially offset by increased experience in field work making the work more efficient and by increased use of automatic and labor-saving equipment.

(c) Project Staff

Project Director - Peter A. Krenkel, Professor and Chairman, Department of Environmental and Water Resources Engineering.

Employed full-time during project year.

Percent of time devoted to project - Approximately 10%.

Co-Investigator - Edward L. Thackston, Assistant Professor of Environmental and Water Resources Engineering.

Employed full-time during project year.

Percent of time devoted to project - full-time during summer, approximately 30% during academic year.

Research Associate - Frank L. Parker, Professor of Environmental and Water Resources Engineering.

Employed full-time during project year.

Percent of time devoted to project - approximately 15% during summer, 5% during academic year.

(d) Reports and Articles Supported by Grant

(1) "Impoundment and Temperature Effect of Waste Assimilation," P. A. Krenkel, E. L. Thackston, and F. L. Parker, Journal of the Sanitary Engineering Division, ASCE, Vol. 95, No. SA1, February, 1969.

(2) "Tracing Polluted Reservoir Inflows with Fluorescent Dyes," Michael W. Morris and Edward L. Thackston, Technical Report No. 18 in Environmental and Water Resources Engineering, Vanderbilt University, May, 1969.